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Evaluation of Methods to Control Air-borne Infections*

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AMONG the new committees of the Association listed in the April issue of the JOURNAL is the Subcommittee for the Evaluation of Methods to Control Air-borne Infections, of the Committee on Research and Standards. This subcommittee was still being formed when that issue went to press, and only the chairman is indicated. Since then the others on the committee have accepted membership and are as follows, in alphabetical order:

F. W. Gilcreas, Assistant Director, Division of Laboratories and Research, New York State Health Department, in charge of Laboratories for Sanitary and Analytical Chemistry.
Alexander Hollaender, Senior Biophysicist, U. S. Public Health Service
Captain Alexander Langmuir of the Army Epidemiological Board's Commission on Acute Respiratory Diseases, Fort Bragg, N. C.
O. H. Robertson, M.D., Professor of Medicine at the University of Chicago, and Chairman of the Army Epidemiological Board's Commission on Air-borne Infections
William F. Wells, Associate Professor of Research in Airborne Infection, University of Pennsylvania Medical School
George M. Wheatley, M.D., Assistant Medical Director of the Metropolitan Life Insurance Company, and Secretary of the American Public Health Association School Health Section
C. P. Yaglou, Associate Professor of Industrial Hygiene, Harvard Medical School.

The formation of this committee is a recognition of the need for a coördinating group representing a variety of professional workers interested in and concerned with the problem of the control of air-borne infection. This problem concerns the bacteriologist, epidemiologist, practising physician and surgeon, hospital administrator, ventilating engineer, illuminating engineer, physicist, health officer, school administrator, plant manager, and office manager (to say nothing of the group most concerned of all, the general public).

The brilliant results from improvement in environmental sanitation as a result of purification of water supplies, proper disposal of sewage, and sanitary production and pasteurization of milk, are in contrast with the failure thus far to control air-borne infections (using the term in its broadest sense to include droplets and dust), with the exception of those few diseases in which there has been developed an effective means of active immunization. If the control of infections of the respiratory tract can be applied at the point of the mode of transmission rather than at the point of

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decreasing the susceptibility of the potential victim, there are certain obvious advantages; namely, (1) protection against many diseases at one time through application of a single procedure, and (2) the protection of large numbers of individuals regardless of their individual understanding of the problem, through application and supervision of the control method by a relatively small group of individuals. These are the same advantages we have enjoyed in eliminating milk-borne outbreaks through pasteurization of milk, and eliminating water-borne outbreaks through improvement of water supplies. The matter is more complicated with regard to air-borne infection, since ordinarily relatively small numbers of individuals are exposed intramurally to a single common air supply, compared to the large numbers of individuals often served by a single water or milk supply.

The current interest in the problem and the tremendous increase in the volume of literature on the subject represent a marked recent change in our conception of air-borne infection. It may be worth while to review briefly the history of changes in our conception of the rôle of air in transmitting communicable diseases, and to outline the problem confronting the new subcommittee.

Following the demonology conception of the etiology of disease the miasmatic theory of the causation of communicable diseases held dominant sway until the end of the last century. Air-borne transmission of disease is such a convenient and reasonable manner of explaining all plagues that its ready acceptance is understandable.

About the middle of the last century, however, and still prior to the development of the science of bacteriology, certain careful epidemiologic studies were made with regard to enteric infections, particularly cholera and typhoid fever by Budd [1] and Snow,[2] respectively, in which it was made clear that these particular diseases were transmitted largely through the introduction of human excreta into water supplies. Since these diseases, as well as all the others, were then explained currently on the miasmatic theory, these demonstrations were serious blows to the theory of air-borne transmission.

When the science of bacteriology was established, following the brilliant work of Pasteur and Koch, these earlier epidemiologic observations concerning cholera and typhoid fever were confirmed, and, furthermore, certain additional experiments were conducted which raised the question as to whether or not there was true air-borne transmission of *any* communicable disease. Some of the earliest of these experiments were reported in 1897 and 1899 by Professor C. Flügge [3, 4] of the University of Breslau, based principally on the work of Laschtschenko.[5] He called attention to the fact that droplets of saliva are thrown off from the mouth during sneezing, coughing, and loud talking, and he also apparently demonstrated, through exposing plates at various distances from the subject, that these droplets quickly settled. He concluded that true air-borne infection other than within a few feet of the "infector" was unimportant.

A further blow was dealt the theory of air-borne infection by Dr. Charles V. Chapin, the eminent sanitarian from Providence, R. I., whose critical evaluation of public health administrative procedures resulted in marked improvement in such practice in the United States during the first third of this century.

Dr. Chapin was born in 1856 and became Superintendent of Health for the City of Providence in 1884, thirteen years before the publication of Flügge's first article mentioned above. He retained this position until June, 1931, a total of forty-eight years, and died in 1941. Throughout his life he was particularly interested in the manner of transmission of communicable diseases, and rightly "debunked" many practices which were in vogue at the time he started his investigations, particularly the practice of terminal fumigation.

One of his most notable contributions was his book *The Sources and Modes of Infection,* first published in 1910 and revised in 1912. One chapter in this book [6] is devoted to the subject of infection by air. The first two sentences of that chapter read: "From time immemorial the air has been considered the chief vehicle of infection. This was but natural, for until recently the virus of the infectious diseases was believed to be gaseous, or at least readily diffusible, and readily borne by air currents." And he concludes this first paragraph with the statement, ". . . the inquiry here made is whether the virus of the infectious diseases is borne by the air, either free or attached to small particles of inanimate matter."

Chapin then goes on to review exhaustively the evidence for and against aerial transmission, discussing the data critically. He places great stress upon bacteriologic findings, particularly the studies by Flügge mentioned above. In this discussion he notes the fact that bacteria have been isolated from the air, and even cautions: "While the tendency is thus away from air infection we must be on our guard lest our generalization carry us too far. It may be a fact that most diseases are not air-borne, and yet further investigation may show that certain other diseases concerning which we are still in doubt may be usually transmitted in this way." [7] Nevertheless, toward the end of the chapter he concludes: ". . . Bacteriology teaches that former ideas in regard to the manner in which disease may be air-borne are entirely erroneous; that most diseases are not likely to be dust-borne, and they are spray-borne only for two or three feet, a phenomenon which after all resembles contact infection more than it does aerial infection as ordinarily understood . . . There is no good clinical evidence that the common diseases are air-borne . . ." [8]

In the last two paragraphs of this chapter, comprising a general discussion, he states:

> In reviewing the subject of air infection it becomes evident that our knowledge is still far too scanty, and that the available evidence is far from conclusive. Yet it is of the greatest practical importance that we should know definitely just what danger there is in air-borne infection, and in what diseases it is to be feared. Infection by air, if it does take place, as is commonly believed, is so difficult to avoid or guard against, and so universal in its action, that it discourages effort to avoid other sources of danger. If the sick room is filled with floating contagium, of what use is it to make much of an effort to guard against contact infection? If it should prove, as I firmly believe, that contact infection is the chief way in which the contagious diseases spread, an exaggerated idea of the importance of air-borne infection is most mischievous. It is impossible, as I know from experience, to teach people to avoid contact infection while they are firmly convinced that the air is the chief vehicle of infection. . . . Without denying the possibility of such infections, it may be fairly affirmed that there is no evidence that it is an appreciable factor in the maintenance of most of our common contagious diseases. We are warranted, then, in discarding it as a working hypothesis and devoting our chief attention to the prevention of contact infection. . . .[9]

It is clear from these statements that Chapin still had an open mind on the subject and that he almost deliberately stressed contact infection out of proportion to the evidence then available as to its relative importance, because he realized that acceptance of an air-borne hypothesis would result in a defeatist attitude so far as important, simple hygienic practices were concerned, such as hand washing.

These views had a tremendous influence in shaping the thought and directing the practice of health officers, particularly in this country. They did indeed discard true air-borne infection as a working hypothesis and seemingly forgot, as well, Chapin's warning as to possible revision of the conception upon further investigation. For almost a quarter of a century air-borne transmission of communicable diseases was assumed to be essentially nonexistent, other than that due to droplet spray within a few feet of the infectious individual. Clinical and epidemiologic observations contrary to this stand were ignored, or in the case of hospital cross-infections of measles and chicken pox, were conveniently considered *ipso facto* evidence of errors in nursing techniques.

Incidentally, these opinions by Chapin concerning air-borne infection are about the only ones he expressed which have not completely withstood the test of time. As Winslow has recently stated:

> In one respect only have the studies of the last twenty years indicated a real modification of Chapin's viewpoint. This is with regard to the importance of aerial dissemination of infection. . . . It seems certain that in the case of the virus diseases the radius of atmospheric dissemination is wider than Chapin thought; and this is probably also true in the case of certain respiratory infections due to bacteria. On the whole, however, the broad principles of the epidemiology of 1910 remains unchallenged; and the application of those principles has been attended with phenomenal success.[10]

The recent reversal of our conception of air-borne infection starts only a little over ten years ago in 1933, when there appeared the first of a series of articles by William Firth Wells, an engineer. In this article, Wells, who was then with the Harvard School of Public Health, described an apparatus he had devised, called an air centrifuge, permitting quantitative determination of bacteria in air with reproducible results under the same conditions, and he concludes: "In the study of the bacterial sources of aerial contamination, experiments have been made to determine under what conditions bacteria are given off by persons confined in a limited space. This inquiry leads also to an investigation of the physical, chemical, and biological properties of droplets in connection with the theory of droplet infection." [11] Here, then, was a better means of accomplishing what Chapin in 1910 had stated was needed to clarify the problem when he said: ". . . As Winslow in his work on sewer air . . . has so clearly pointed out, a quantitative examination of the floating bacteria is necessary if we wish to determine the real danger from the inhalation of the air." [12]

In 1934, Wells published two papers simultaneously entitled "Droplets and Droplet Nuclei" [13] and "Viability of Droplet Nuclei Infection," [14] reporting on the results of experiments conducted in the spring and summer of 1933 and presented before the American Association for the Advancement of Science on December 27, 1933. In the first paper he points out that although it is true that larger droplets ejected at the height of two meters or, roughly, the height of a man, will fall to earth within a few feet of the source, smaller droplets evaporate so rapidly that they will evaporate before they will settle to the ground, leaving in the air, in a state of suspension, the bacteria or other particulate matter contained in the droplets. These so-designated "droplet nuclei" remain suspended indefinitely and are readily wafted by air currents. He finds that "Somewhere between .1 and .2 mm. (diameter) lies the droplet size which identifies the droplets of mouth spray that reach the ground within the life of the droplet as against droplets that evaporate and remain in the air as droplet nuclei with attached infection." Although temperature and humidity, and the presence of dissolved substances affect the rate of evaporation to a certain extent, droplet size is the predominating factor.

To demonstrate the actual occurrence of such droplet nuclei, he adopted Tyndall's experiments on atmospheric dust by constructing a tight cylindrical tank 7 feet long, and of the same diameter, along the axis of which was projected a powerful beam of light. Ports along the side of the tank gave a perpendicular sight on the beam, revealing any suspended particles entering its path. When pure water was atomized into this beam it appeared like steam in cold air, which subsided completely when the spray ceased, with the light beam then completely invisible. When an atomized suspension of *Bacillus subtilis* was injected, a delicate pale blue smoke band remained in the path of the beam. Even after this disappeared and the beam became invisible, Wells was able to collect living bacteria from the air by attaching his air centrifuge to the tank and, in fact, was able to recover bacteria from the interior of the tank a week after inoculation.

In his conclusions, Wells states:

> Droplet infection is essentially localized and concentrated while infection broadcast by droplet nuclei is dispersed and dilute. Thus, it readily escapes detection by the instruments previously devised for atmospheric exploration. Failure to discover air-borne infection bacteriologically no more proves its absence, therefore, than failure to isolate *B. typhosus* from a sewage polluted water proves that typhoid fever cannot be conveyed by drinking water.

In a second paper [14] he reports on testing in the same chamber by the same method atomized suspensions of pathogenic bacteria which, of course, are more delicate than *B. subtilis*. He found that he could recover pneumococci, streptococci, and diphtheria bacilli 24 hours after the original atomization. He concludes that these results make apparent "that the time and distance droplet nuclei may travel depend more upon the viability of the organisms in air than upon settling rates."

These experiments, then, clearly indicated that exposure of open plates, which was the bacteriologic procedure employed by early investigators and which led to the conclusion that viable organisms were expelled only a few feet by human beings, was an unreliable method of determining the infectiousness of air since small particles do not settle and thus would not be "registered" on the plates; the plates catch only the larger droplets which fall to earth close to the subject.

The next step was actual demonstration of infection in animals in such a manner that the microörganisms or viruses definitely were carried by the air stream, with elimination of the possibility of direct droplet infection. These experiments, conducted by Wells and others,[15-22] involved such successful transmissions as influenza to ferrets and mice, tuberculosis to rabbits, and poliomyelitis to monkeys.

With the development of these experimental techniques it was possible to experiment with agents which might prevent such air-borne transmission. Such experimentation has extended principally in four directions: (1) physical barriers (face masks, filters, cubicle and room partitions, and control of air currents through differential air pressure),[23-25] (2) disinfection of air through ultra-violet radiation,[15, 16, 21, 26-34] (3) disinfection of air through the use of disinfectant vapors,[35-43] and (4) laying of dust and lint through application of oil to floors and bedding.[44-48]

The problem as a whole, then, facing the Subcommittee for the Evaluation of Methods to Control Air-borne Infections may be summarized as in Table 1.

The above indicates the scope of the problem but the subcommittee decided at its first meeting on June 4 that it does not consider it within its province to evaluate control methods concerned with the primary reservoir (isolation and quarantine, chemotherapy, and

TABLE 1

Possible Methods to Control Air-borne Infections in Enclosed Spaces

Point of Application	*Method of Control* (Considering only enclosed atmospheres)
1. At reservoir of infection	
a. primary (human; atomization)	1. isolation and quarantine
	2. chemotherapy
(1) droplets	3. other methods of rendering non-infectious
(2) droplet nuclei	(e.g., tonsillectomy in diphtheria)
b. secondary (inanimate; turbulence)	oiling
(1) dust	
(2) lint (bedding, clothes, bandages, etc.)	
2. At susceptibility of individual	1. vaccines and sera
	2. chemoprophylaxis
3. At mode of transmission from reservoir to susceptible individual	1. mechanical (physical barriers)
	a. masks
	b. partitions
	c. differential air pressure (controlled currents)
	d. filters
	2. dilution of air
	3. reduction in crowding
	4. disinfectant radiation
	a. daylight
	b. artificial illumination
	(1) visible light
	(2) ultra-violet light
	5. disinfectant vapors

other methods to render the individual non-infectious). Nor is it concerned with reducing susceptibility of individuals to such infections (vaccines, sera, and chemoprophylaxis). Conversely, it considers its function to extend beyond the scope indicated by the table in that it is definitely concerned with the true relative importance of modes of transmitting infections of the respiratory tract by media other than the air.

The subcommittee plans to present its findings in a series of annual reports (possibly more frequently when indicated), presenting critical summaries of published papers bearing on the problem, and giving specific recommendations as to application of the various control procedures. In this evaluation it will use the technical advice available through other committees of the Association concerned with this problem* and will work closely with comparable committees of other organizations, such as the Committee on Air Sterilization and Odor Control of the American Society of Heating and Ventilating Engineers, the Committee on Air Sterilization of the American Hospital Association, and the Council on Physical Medicine of the American Medical Association.

* Particularly the Laboratory Section's Standard Methods Committee for the Examination of Germicides and Antibacterial Agents with Associate Referees for Disinfection of Air by Germicidal Vapors and Mists (O. H. Robertson), and for Disinfection of Air by Ultra-violet Irradiation (Alexander Hollaender); and the Industrial Hygiene Section's Committee on Standard Methods for Examination of Air, with Subcommittee on Bacteriological Procedures (W. F. Wells, Chairman).

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